<Note>Combustibility of China Fir Wood Treated with Standard Fire Retardants

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Note

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Abstract——Test specimens were prepared from China fir (*Cunninghamia lanceolata* Hook), and impregnated with five fire retardant chemicals listed in Chinese National Standards (CNS). The treated specimens were tested for their combustibility according to CNS 6532 to measure the time required for the temperature of the exhausting air to exceed the standard referential curve, heat generation, factor of smoke, time of after-flame, and occurrence of cracks of the test. Comparison of the results demonstrated that three chemicals could meet requirements in the standard.

Keywords: China fir, Combustibility, Ignition, Smoke, After-flame.

1. Introduction

China fir is one of the trees which are abundantly distributed and widely used as notable building components in Taiwan. Although various physical and chemical properties were studied, fire performance of the species has never been examined according to the standard method.

The main purpose of this study was to investigate the fire performance of China fir solid wood treated with different fire retardants.

2. Experiment

2.1 Treatment

2.1.1 Specimens

Specimens measuring 210×210×9 mm prepared from China fir (*Cunninghamia lanceolata* Hook). All specimens were conditioned in a room at 20±1°C and 64±1% RH for over 30 days.

2.1.2 Chemicals

Chemicals used in the present investigation were five fire-retardants listed in Chinese National Standards (CNS 4180–CNS 4184). The chemical components are shown in Table 1.

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Table 1. Composition of fire-retardant chemicals used.

Composition	Chemical Types				
	A	B	C	D	E
$ZnCl_2$	80%	65.2%	—	35%	—
$Na_2Cr_2O_7.2H_2O$	20%	14.8%	—	5%	—
$(NH_4)_2SO_4$	—	10.0%	60%	35%	—
H_3BO_3	—	10.0%	20%	25%	—
$Na_2B_4O_7$	—	—	10%	—	—
$(NH_4)_2HPO_4$	—	—	10%	—	92%
$As_2O_5.2H_2O$	—	—	—	—	4%
NaF	—	—	—	—	4%

Note; Type A : CNS 4180, Type B : CNS 4181, Type C : CNS 4182, Type D : CNS 4183, Type E : CNS 4184, CNS : Chinese National Standards.

2.1.3 Chemical treatment

The chemicals were prepared as aqueous solutions, and their concentrations ranged from 10% to 40% by weight. After taking measurement of weight [W_1 (kg)] and volume [V (m^3)] of the conditioned wood specimens they were put in a treating vessel containing one of the test chemical solutions. Eight replicates were prepared for each treatment.

The pressure of the treating cylinder was kept at 6 ± 0.5 kgf/cm^2 for three hours, and the remaining solution was removed after lowering the pressure to atmospheric condition. The specimens were kept in the tank with a little chemical for 24 hours to unify the chemical content in the specimens.

The treated specimens were then taken out and reweighed [W_2 (kg)]. The formula mentioned below was used to calculate the chemical retention in these specimens. $R=(W_2-W_1)\times C/V$, where "C" means the treating concentration of the chemical.

2.1.4 Moisture condition after treatment

All the treated specimens were stored indoors for at least 72 hours, and then moved into the moisture conditioned room for longer than 14 days. After conditioning, the specimens were put in an oven 40 ± 1°C for 72 hours, and then stored in a desiccator for 24 hours before testing their combustibility.

2.2 Combustibility

2.2.1 Testing Method

The major tests were conducted according to Chinese National Standars (CNS) No. 6532 class 3, which is similar to JIS-A-1321. The instrument with the code of F2-R3 from Toyoseiki Co. Ltd., Japan, was used for testing of combustibility. It was equipped with furnace, smoke chamber, photometer, and operational panel as shown in Fig. 1.

The test of surface combustibility lasted for six minutes. During the initial stage of the heating process, liquefied petroleum gas (LPG) was introduced to the test apparatus for

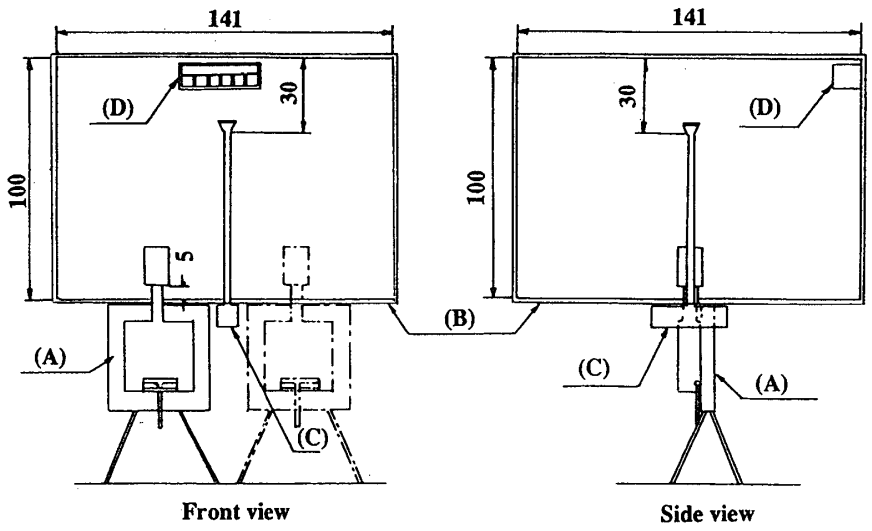

Fig. 1. Apparatus for measuring combustibility (unit: cm). Note; (A) Furnace, (B) Smoke chamber, (C) Photometer, (D) Smoke stirrer.

three minutes, and then electric heater was provided as a major heating source.

This testing method was designed to simulate the heating process of the actual combustion.

2.2.2. Characteristics in combustibility

Following characteristics were measured to compare the combustibility of the treated materials.

a) The time required for the temperature of the exhausting air to exceed the standard referential curve (tc) : factor of igniting ability or ease of ignition. A material that has a small "tc" means the easiness to catch fire. In CNS 6532, a material of class 3 should have its "tc" of larger than three minutes (180 seconds).

b) Heat generation ($td\theta$) : an area enclosed by the curves of exhausting air temperature of both the test specimen and the standard reference as shown in Fig. 2 (unit : min·°C). A material that has a larger "$td\theta$" is corresponding to easiness of heat generation. A material of class 3 should have its "$td\theta$" of smaller than 350 min·°C.

c) Factor of smoke (C_A) : the largest smoke generation in a test. C_A is calculated as follows;

$CA = V/L \times A \log \frac{I_0}{I} = 240 \log \frac{I_0}{I}$ where "V" means the volume of a diffusion space, i.e., the volume of the smoke chamber ($2\ m^3$) ; "L" is the length of the light detection device (25 cm) ; "A" is the area of specimen that was exposed to fire ($18\ cm \times 18\ cm$) ; "I_0" is the lowest light density at the beginning (l_x), and "I" is the lowest light density in a testing period (l_x). A material of class 3 should have its "C_A" smaller than 120.

d) Time of after-flame : linger time of flame existed in the surface of the material after heating was stopped. It also means the self extinguishable ability of a specimen. A

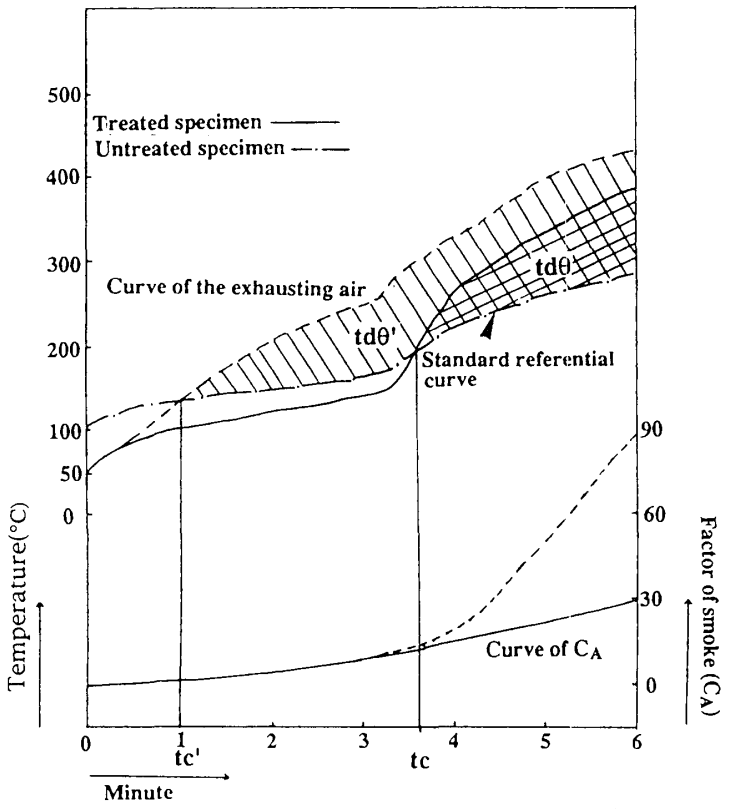

Fig. 2. Explanation of measurement of combustibility characteristics. Note; *tc* and *tc'*: the time that the temperature of the exhausting air exceed the standard referential curve for treated and untreated specimens, $td\theta$ and $td\theta'$: heat generation of treated and untreated specimens, C_A: factor of smoke.

material of class 3 in CNS 6532 should have its flame linger time of shorter than 30 seconds. In this research the observation of the after-flame was extended to three minutes (180 seconds). If a specimen continued the flaming over three minutes, the time of after-flame was recorded as three minutes.

e) Occurrence of cracks : If a test material performs well, no cracks could be observed in the rear surface of the specimen. If crack happened it might cause the spread of fire as well as the strength loss. According to the standard, if cracks appear in the rear surface, they should be narrower than one tenth of the thickness of the specimen.

3. Results and Discussion

3.1 Time required for the temperature of exhausting air to exceed the standard referential curve (*tc*)

As shown in Figs. 3–7, most of the chemicals tended to delay the ignition at higher retentions. The chemicals except A are effective in enhancing incombustibility[1-4].

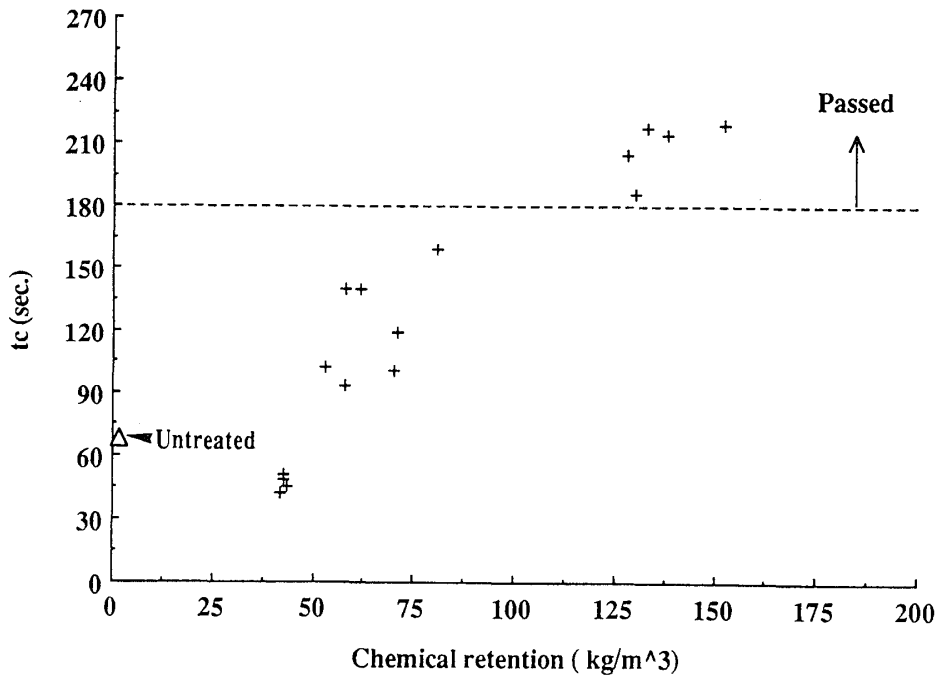

Fig. 3. Time required for the temperature of exhausting air to exceed the standard referential curve (*tc*) chemical A.

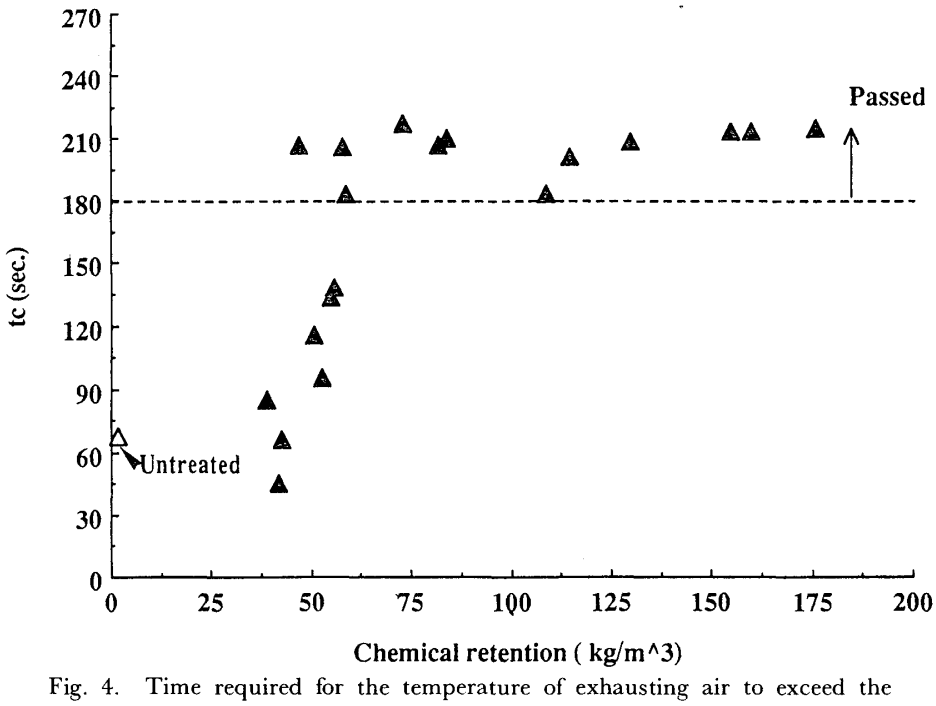

Fig. 4. Time required for the temperature of exhausting air to exceed the standard referential curve (*tc*) chemical B.

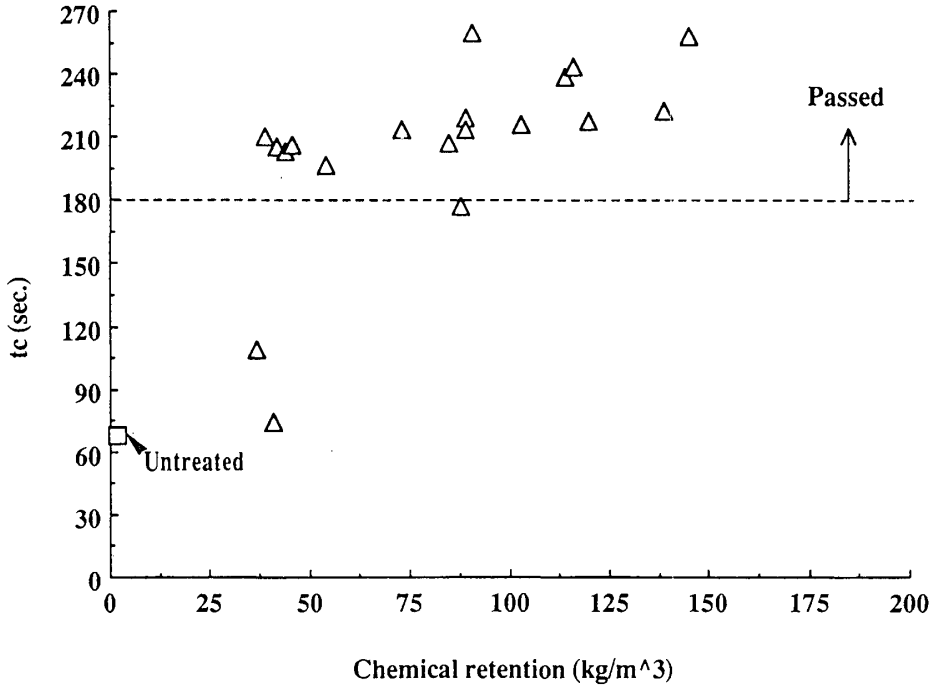

Fig. 5. Time required for the temperature of exhausting air to exceed the standard referential curve (*tc*) chemical C.

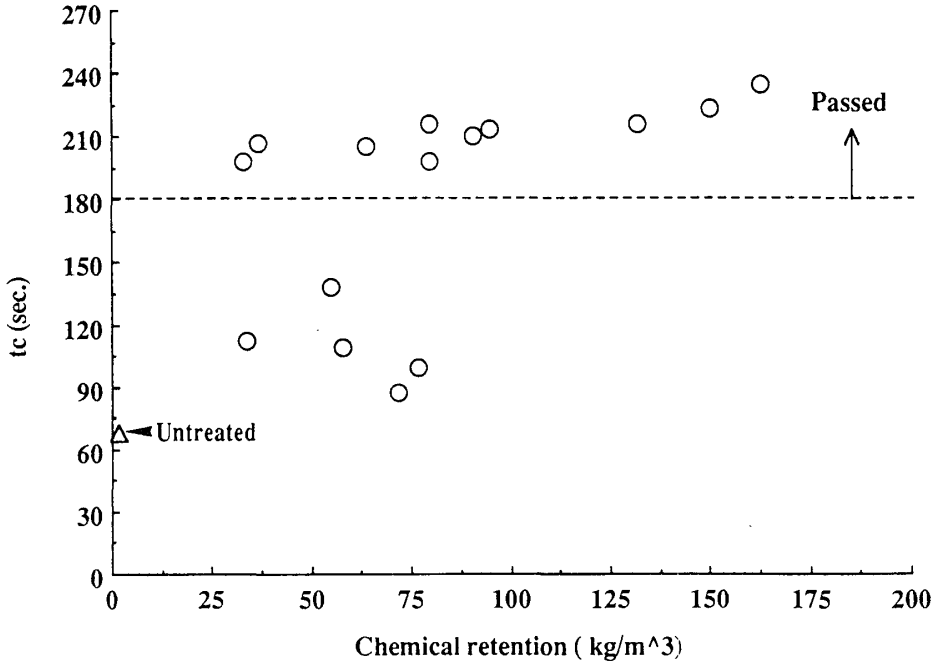

Fig. 6. Time required for the temperature of exhausting air to exceed the standard referential curve (*tc*) chemical D.

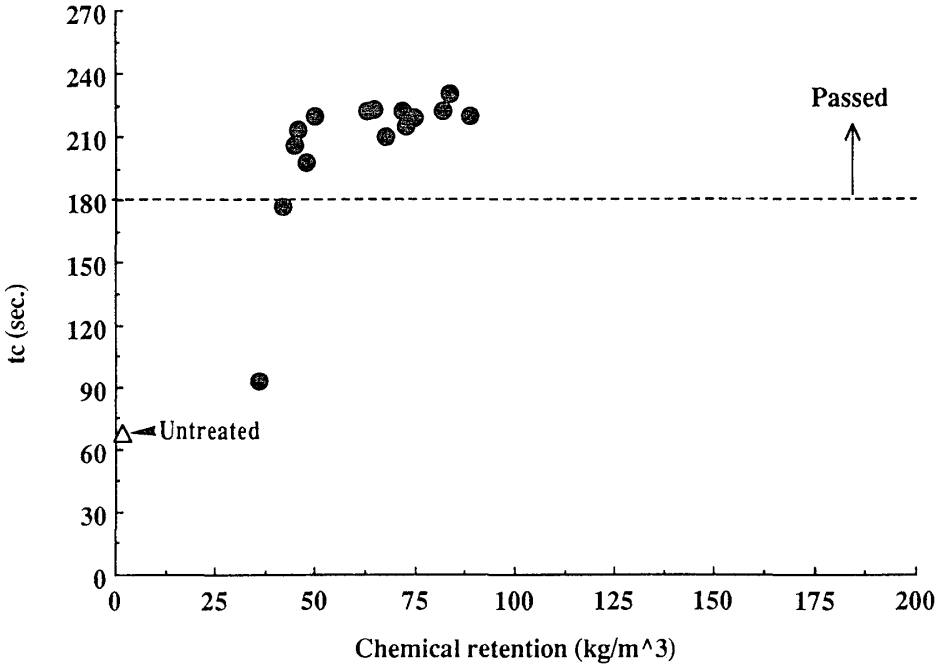

Fig. 7. Time required for the temperature of exhausting air to exceed the standard referential curve (tc) chemical E.

3.2 Heat generation ($td\theta$)

Almost all of these chemicals were effective in reducing the heat release regardless of retention levels (Figs. 8–12).

However, even untreated solid wood could sometimes show their heat generation ($td\theta$) under 350 min·°C. That was well coincident with the former results[5–7].

3.3 Factor of smoke (C_A)

The relationships between chemical retention and "C_A" are shown in Figs. 13–17.

Some specimens treated with chemicals B and D had a tendency of increase in factor of smoke. When at higher chemical loadings, it is considered difficult for the specimens to catch fire, and heat generation was not sufficient to burn them totally[3]. Particles of char and volatile should spread from the surface of these specimens into the smoke chamber. Therefore, the "C_A" of these specimens become larger than those of lower chemical retentions.

All of the test chemicals performed well and meet the requirement in the standard.

3.4 Time of after-flame

Most specimens failed in meeting the requirement in the standard. As shown in Figs. 18–22, time of after-flame was the critical characteristic for all the test chemicals this time. Only a few specimens treated with chemicals B, C and D were self extinguishable within 30 seconds.

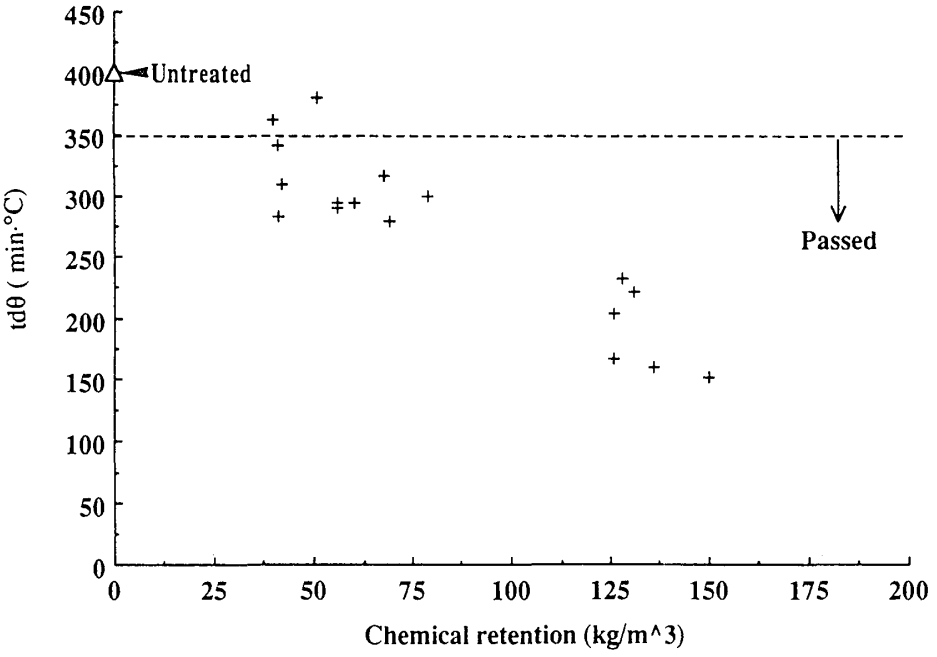

Fig. 8. Heat generation ($td\theta$) chemical A.

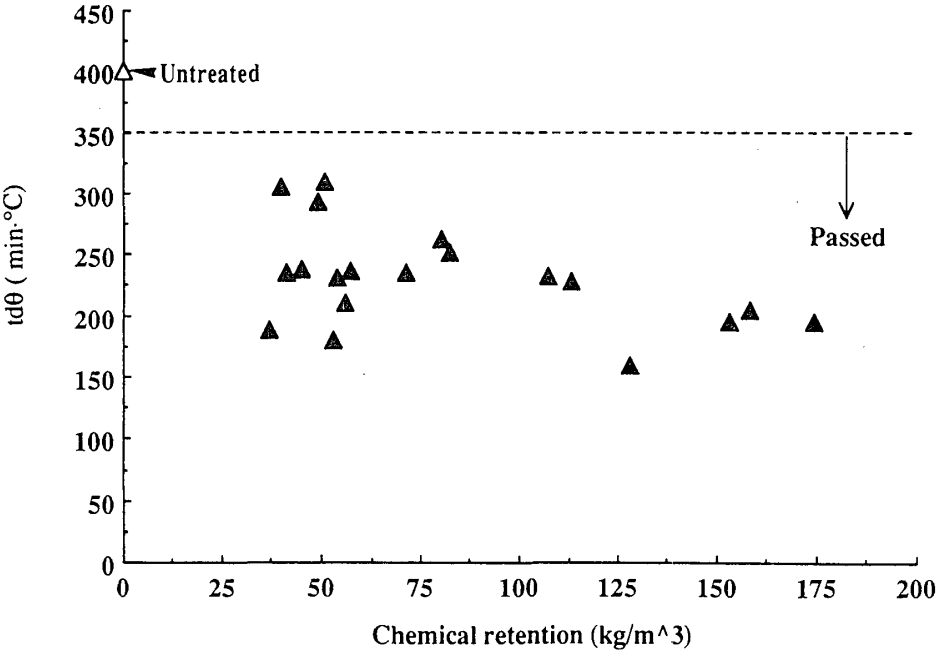

Fig. 9. Heat generation ($td\theta$) chemical B.

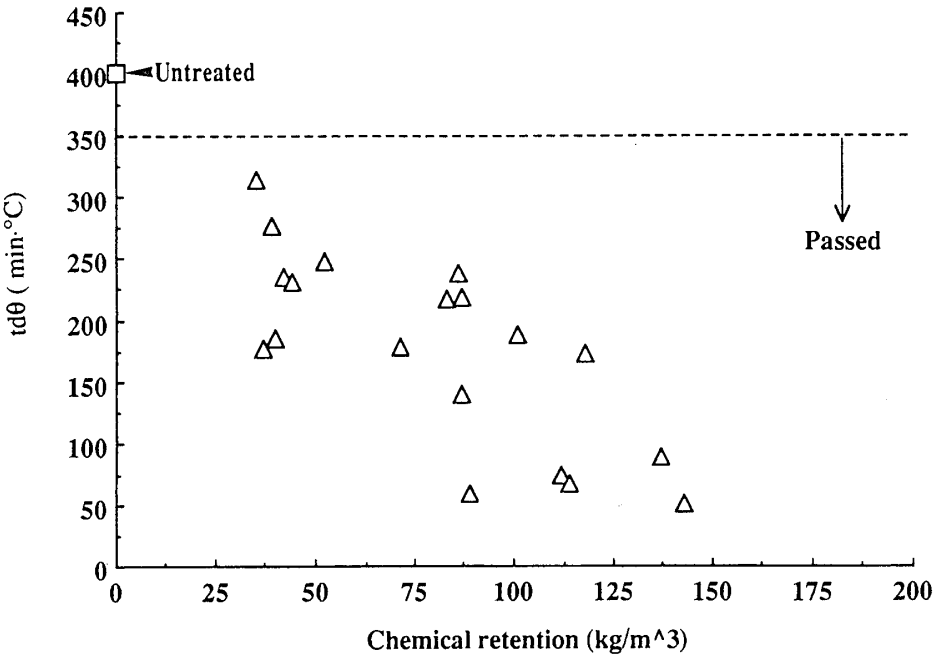

Fig. 10. Heat generation ($td\theta$) chemical C.

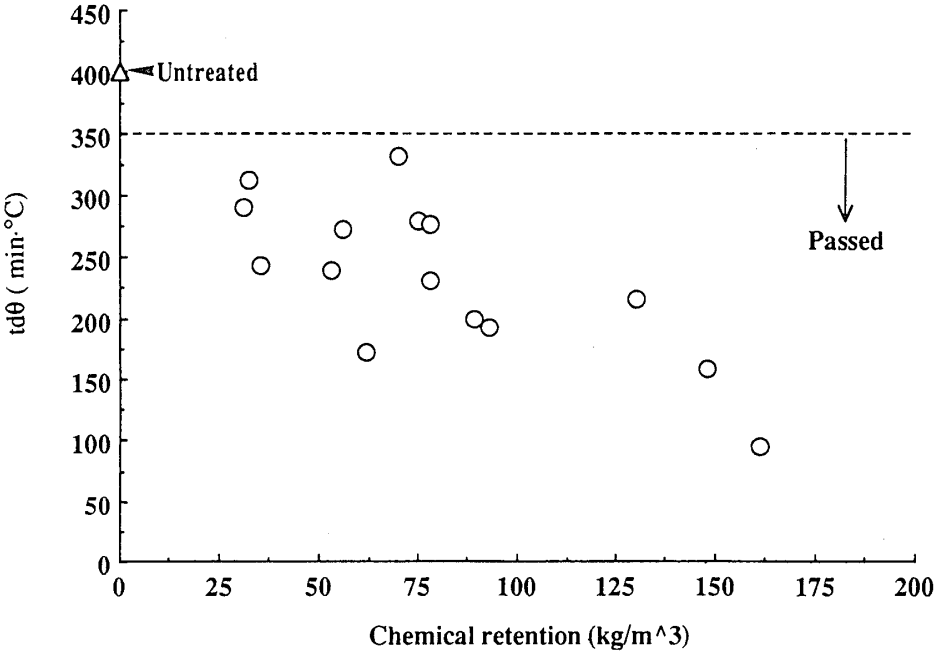

Fig. 11. Heat generation ($td\theta$) chemical D.

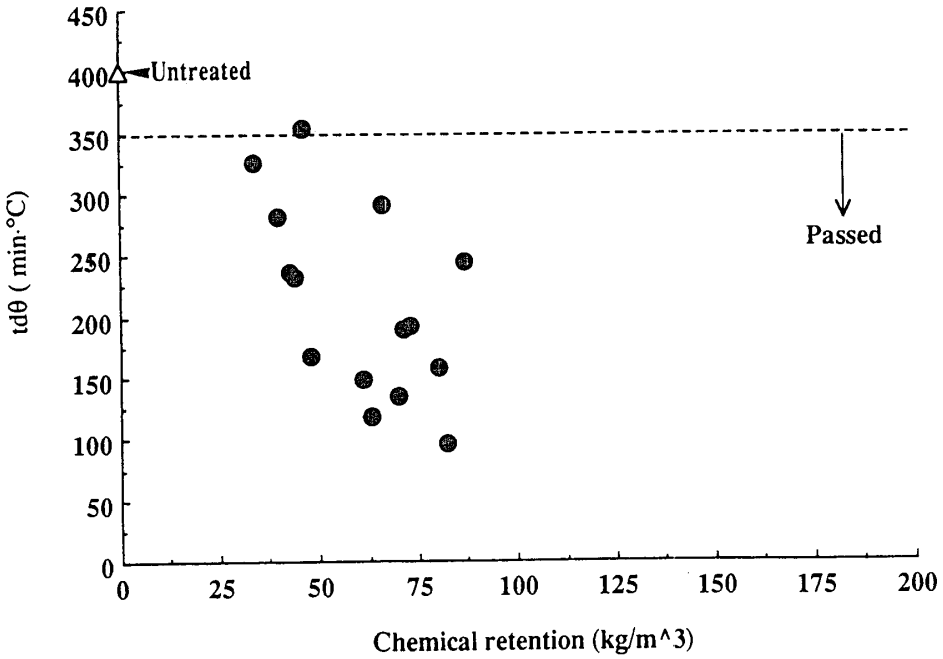

Fig. 12. Heat generation ($td\theta$) chemical E.

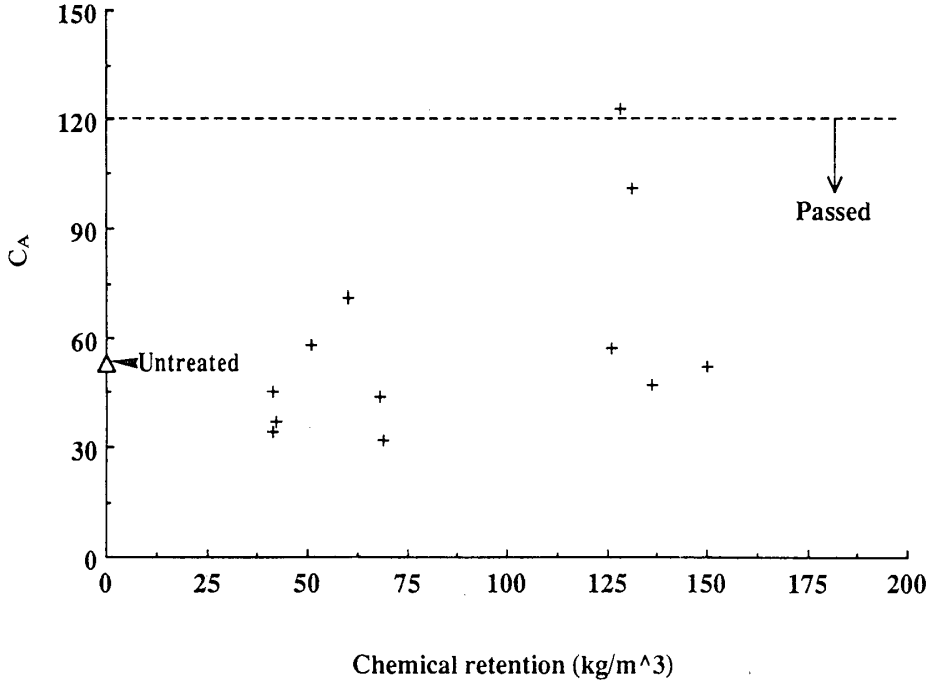

Fig. 13. Factor of smoke (C_A) chemical A.

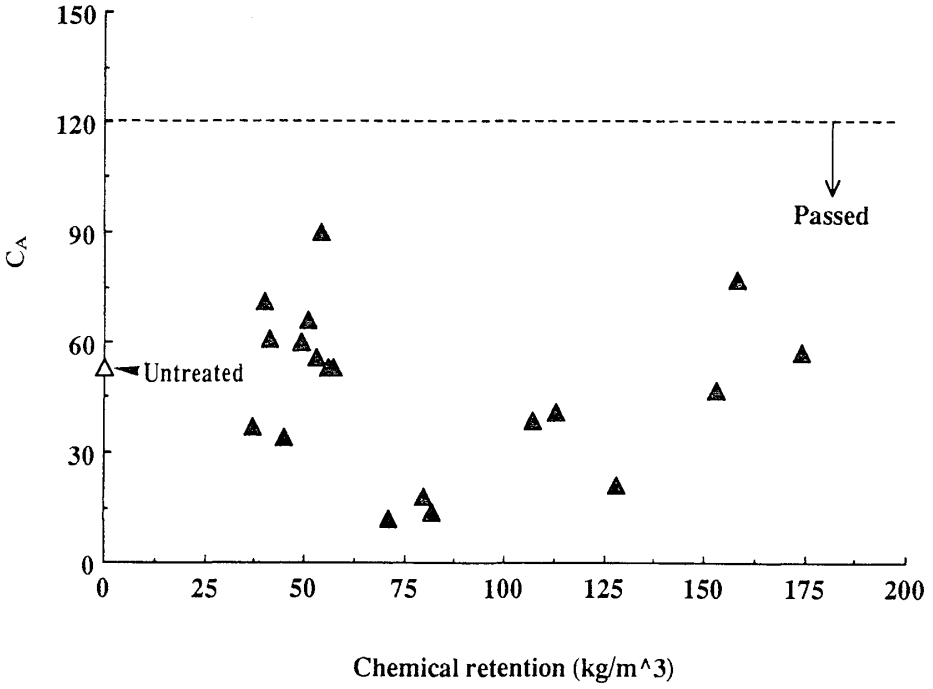

Fig. 14. Factor of smoke (C_A) chemical B.

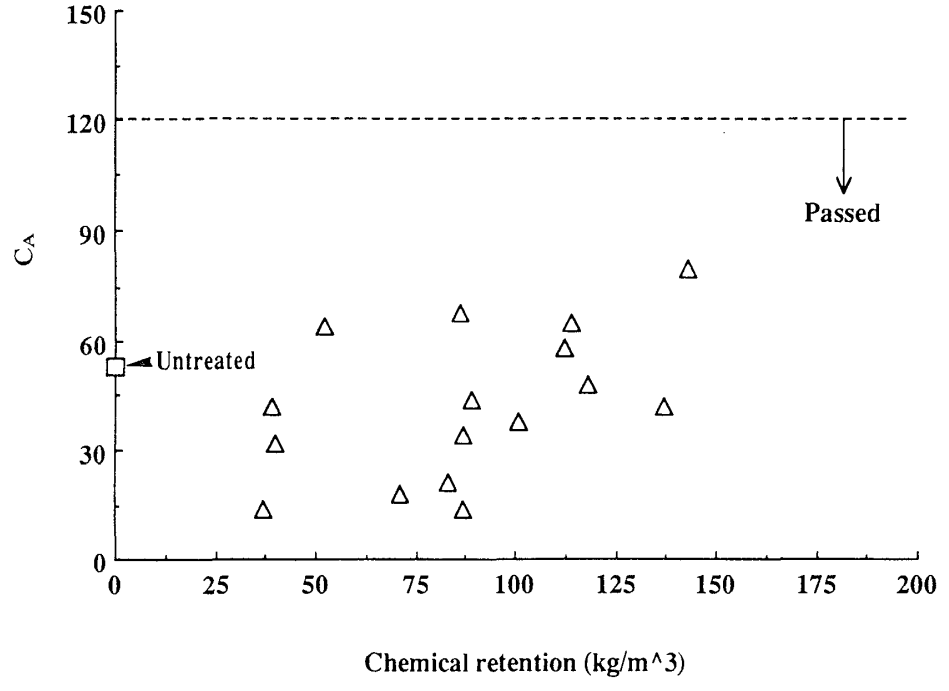

Fig. 15. Factor of smoke (C_A) chemical C.

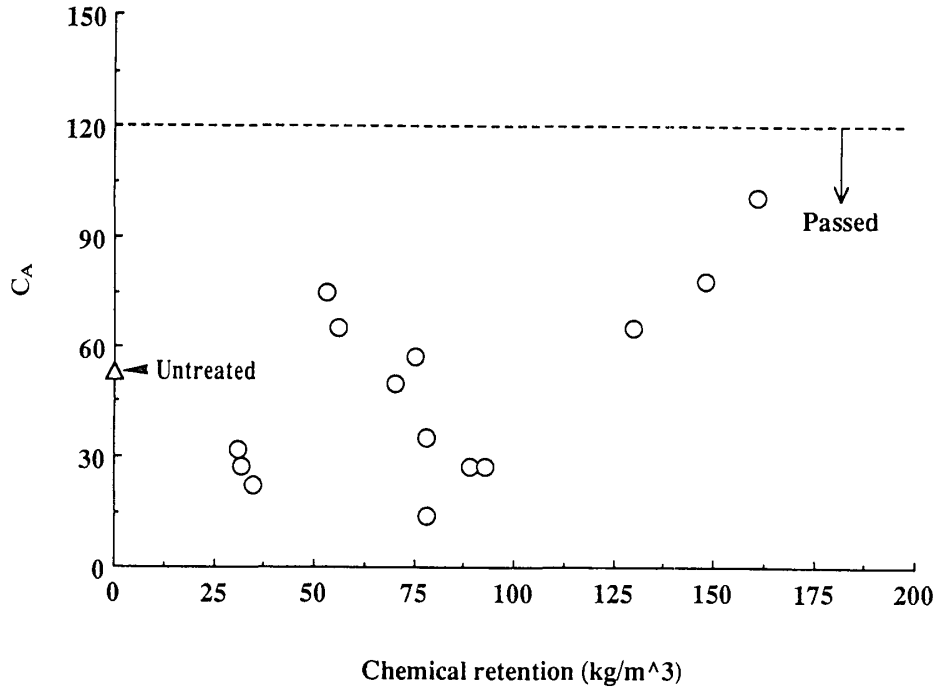

Fig. 16. Factor of smoke (C_A) chemical D.

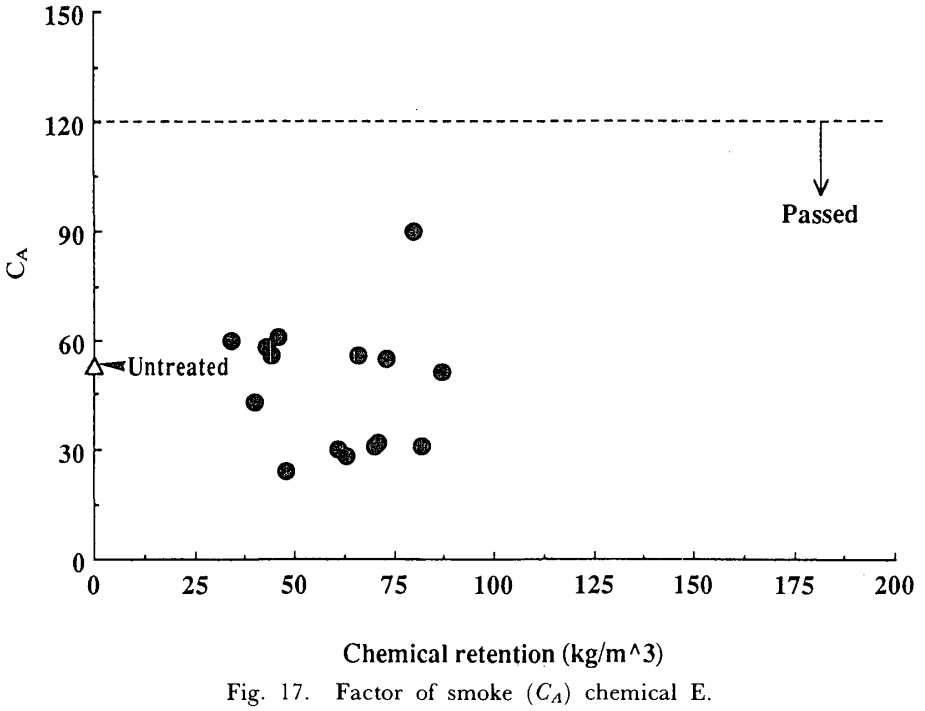

Fig. 17. Factor of smoke (C_A) chemical E.

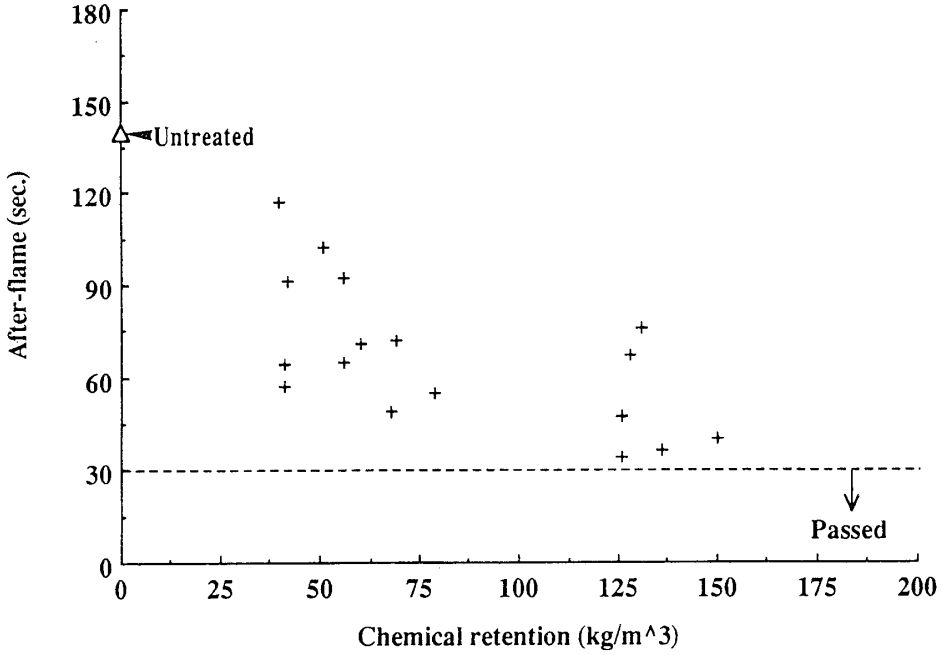

Fig. 18. Time of after-flame chemical A.

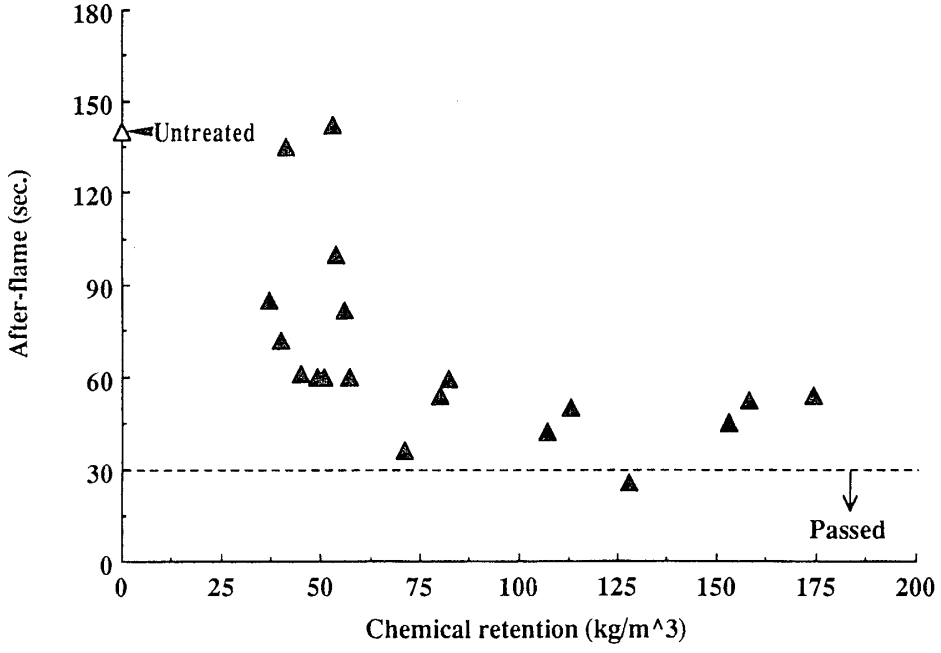

Fig. 19. Time of after-flame chemical B.

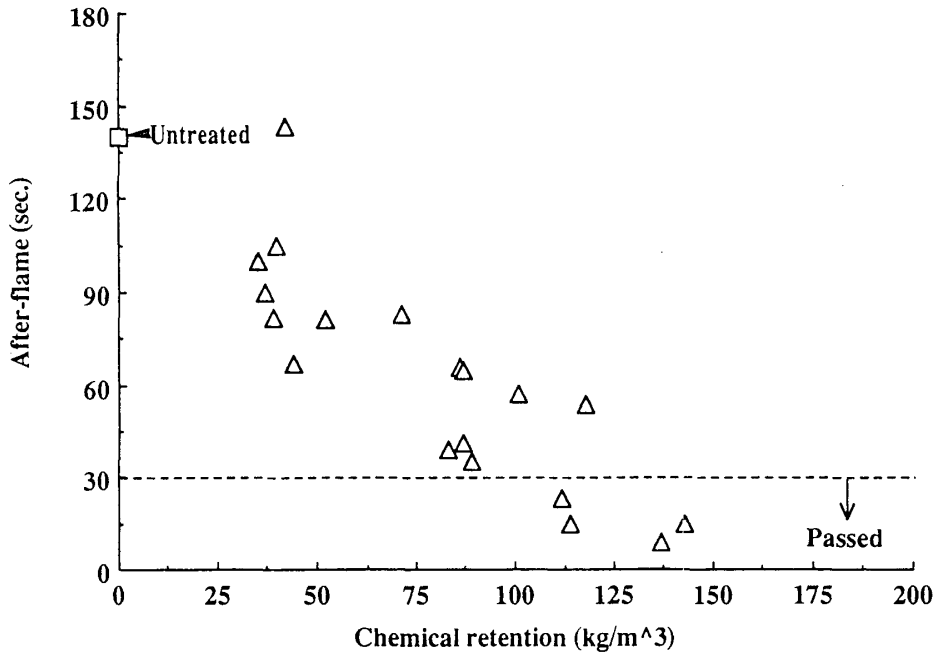

Fig. 20. Time of after-flame chemical C.

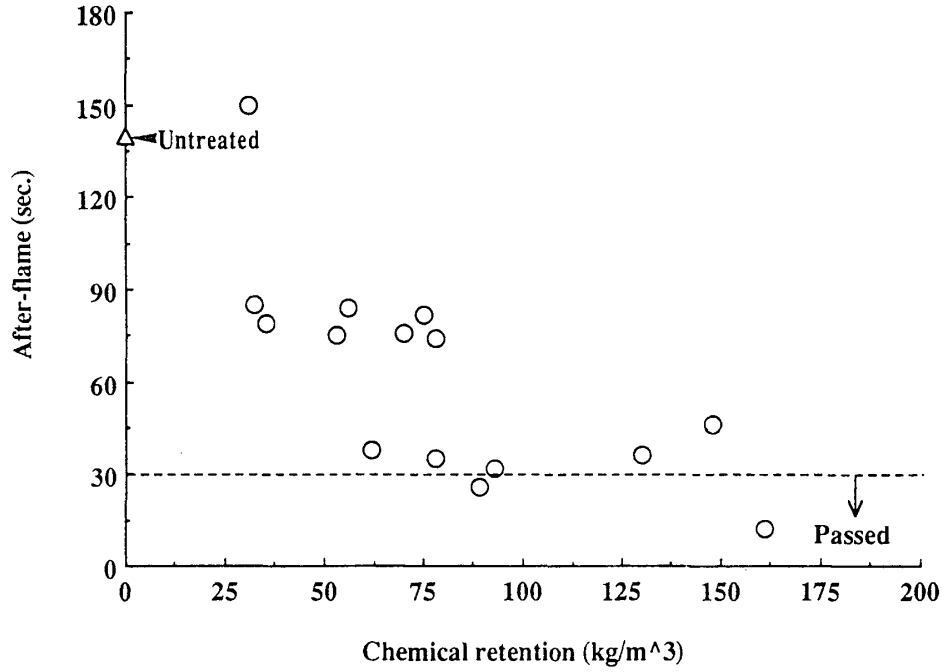

Fig. 21. Time of after-flame chemical D.

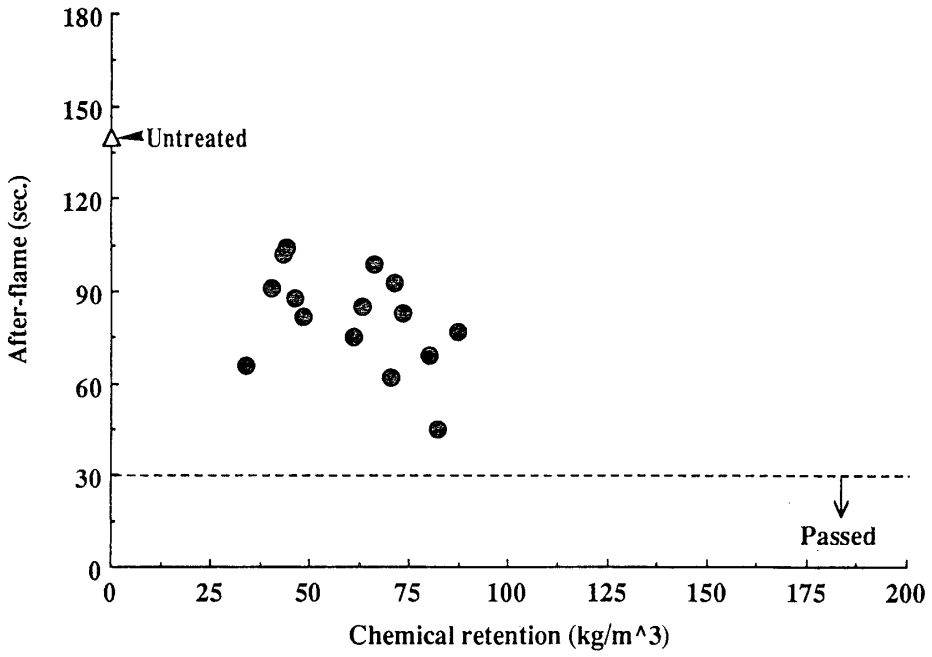

Fig. 22. Time of after-flame chemical E.

3.5 Occurrence of cracks

Most of specimens treated with chemicals C and E passed this standard (Table 2) as they did not have any crack on the rear surface or any crack wider than one tenth of their thickness.

Table 2. Cracks on the rear surfaces of the treated specimens.

Chemicals	Specimen No.																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	—	—	—
B	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O	X	O	O	X	—
C	O	O	X	O	O	O	O	O	X	O	X	O	O	O	O	O	O	O	O	—
D	X	X	X	X	X	X	O	X	X	X	X	X	O	O	O	—	—	—	—	—
E	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	—	—	—	—	—

Note; O: no crack or little cracks acceptable to the standard, X: failed.

Undesirable cracks took place on other specimens. Some metal elements, such as zinc and chrome were not considered to well blend with the cell wall components of wood[3]. The anisotropic shrinkage might widen the small cracks when the specimen was heated.

4. Conclusions

The fire-retardant chemicals tested in this research were effective in protecting wood from catching fire. However, the time of after-flame was the common critical factor for the

chemicals.

Combustibility tests demonstrated that three chemicals (B, C and D) could meet the standardized requirements. Chemical D performed well at the retentions of 89 and 161 kg/m^3. And the same was observed for chemical C at the retentions of 112, 114, 137 and 143 while chemical B meet the requirements, only at the retention of 128 kg/m^3.

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